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A HISTORICAL REVIEW OF UNDERWATER ACOUSTIC TECHNOLOGY 1916-1939 WITH EMPHASIS ON UNDERSEA WARFARE

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ABSTRACT

In this review, the author describes the complex interrelating elements that shaped the development of undersea warfare technology, first during World War I, and then during the 21 years between the wars. During World War I, the U-boats were barely countered—*not* defeated. After the war, the resumption of submarine warfare against merchant shipping was not planned for or considered likely by any of the nations of the world. Between wars, the United States developed and trained a submarine force for Fleet operations planned to counter Japanese naval threats. In the acoustic area the restricted German navy (with no submarines until 1935) stressed *passive*, while the United States and United Kingdom stressed *active* sonar developments. The German system became the electrically-steered conformal array GHG, first developed for capital surface ships and then later for submarines. The U.S./U.K. developments, although independently pursued, resulted in similar hardware, i.e., mechanically steered QC types for surface ships, and mechanically-steered active-passive (QC-JK types) for submarines. When naval war unexpectedly resumed in 1939, neither Germany nor Britain were prepared for a resumption of the U-boat war against shipping.

INTRODUCTION

Naval underwater acoustic technology had its beginnings in World War I when the U-boats sank over 4,800 merchant ships. As a consequence, passive and then (after 1918) active sonars were developed which, with depth-charge weapons, challenged the invulnerability of the submerged submarine.

As described in a previous paper,* the documentation of the submarine warfare effort prior to World War II is scarce and scattered. The efforts in military technology, especially in underwater acoustics, were not at all compiled and collated in the effective manner of the National Defense Research Committee (NDRC) and the Office of Scientific Research and Development (OSRD) during and after World War II. Dr. Elias Klein[2] and Dr. Albert Beaumont Wood[3] have written invaluable memoirs of their work in underwater sound research and applications prior to 1939. However, these memoirs emphasize "what was done" at each of their laboratories without describing the historical developments that determined "why it was done." Hinted at, but not detailed, was the historical background associated with the development of pro- and anti-submarine warfare acoustic technology.

This paper will retrace some World War I developments with more historical detail than in Ref. (1). Then in the same vein, the interrelated historical and technical developments for the 1919-1939 interval will be described with special emphasis on the United States, Britain, and Germany.

To the author's knowledge, there has been no prior attempt to produce an interrelated article of this type. In the beginning he describes haval considerations; he next details various interfaces with political events; and finally he outlines the technical developments. Interspersed throughout the paper are charts and figures to assist the reader in "switching gears" between the diverse elements that constitute this article.

*References listed at end of article.

ANTI-SUBMARINE WARFARE—1914-1918

Strategic and Tactical Considerations Through 1917 (British View)[4]

Naval tacticians on both sides during World War I expected that eventually the main British Fleet, the "Grand Fleet," would engage the German Fleet, the "High Seas Fleet," based on the North Sea ports of Germany. The British forces outnumbered the German; hence, the German Navy hoped that the deterioration of their opposing naval submarine and mine forces, due to attrition, would improve their chances of success in the final engagement. This did not occur; the mines were easily swept; and the submarine's main success was against merchant shipping.

The most important naval engagement of WWI was the Battle of Jutland in June 1916. Although the British losses exceeded the German (a tactical defeat for the British), never again did the German Fleet venture forth to give battle (a strategic victory). However, the British Grand Fleet was maintained at high readiness, expecting that as the German tactical needs required, the surface forces would be committed.

Strategic and Tactical Considerations Through 1917 (German View)[5]

In 1914, the Kaiser (and later on Hitler) hoped that his mighty army would win a quick victory on land. Top priority for the assignment of resources went to the army throughout the war—the role of the navy was secondary. While the armies advanced in France, the role of the navy was to hold off attacks of the British Fleet. If possible, submarines were to sink enemy *warships* to improve the numerical balance between the Grand and High Seas Fleets.

Submarines, however, because of their vulnerability on the surface (to gunfire or ramming) and poor maneuverability when submerged, proved to be relatively ineffective against high-speed warships, but efficient killers of lumbering merchant ships.

Therefore, when in 1916 the land war was in a stalemate, the German Admiralty, in the person of Admiral von Tirpitz, attempted to persuade the German Chancellor to adopt "unrestricted" naval warfare, that is, sinking at sight without allowing the crew to take to lifeboats. Tirpitz argued that if the submarine came to the surface at close range it could be exposed to fire from an armed merchantman or a decoy ship; if it surfaced at a distance the ship could escape. In January 1916, the German Naval staff presented a memorandum claiming that unrestricted warfare would force England to make peace in 6 months. Chancellor Bethmann, distrustful of the military, vacillated because of his concern that the resultant loss of life from unrestricted warfare would bring America into the war.

Admiral von Tirpitz, in despair at the delay, resigned. He was replaced by Admiral von Capelle, a less forceful naval officer who delayed the full expansion of submarine production by 90 boats. *(This program delay in 1916 hurt Germany badly in 1917 and 1918, and in the opinion of some observers, lost the war.)* In the autumn of 1916, however, the German Admiralty found powerful allies in the German army. One year after Adm. von Tirpitz proposed the plan, on January 31, 1917, Germany declared unrestricted submarine warfare in identified zones around the British Isles, the Mediterranean, the Azores, and in March 1917, Archangel. As Chancellor Bethmann feared, the losses of life and material to U-boat attacks caused great indignation in America.

The effects of the new campaign beginning in February 1917 were quickly felt. The system under which traffic approached Britain on routes patrolled by ships, trawlers, and a sprinkling of destroyers proved incapable of meeting the emergency. Losses in merchant ships rose from 171 in January to 234 in February to 281 in March and 373 in April—the month that the United States entered the war. This pace was ruinous; Britain would really be starved into submission by the end of the summer. The opera-

tional situation was also critical—the British Fleet was confined to its bases for there was only an 8-week supply of fuel oil in England.

Table I shows the desperation of the Allies. In 1917, more than 6,000,000 tons of shipping were lost.

TABLE I. Allied and Neutral Ships Lost and Constructed During World War I (Gross Tons)

PERIOD	LOST	CONSTRUCTED	TOTAL TONNAGE (CONSTRUCTED-LOST)
1915	1,744,657	1,202,000	- 542,657
1916	2,799,772	1,688,000	-1,111,792
1917	6,623,623	2,937,786	-3,685,837
1st qtr.	1,146,920	870,317	- 276,603
2nd qtr.	963,370	1,243,274	+ 279,904
3rd qtr.	892,546	1,384,130	+ 491,584

(Source: D.L. George, *War Memoirs* (Little Brown, 1934), pp. 132-133)

American Effort 1917-1918—ASW Priority

America's entry into the war in April 1917 brought limitless resources to the Allied side, but only in a comparatively distant future. The Navy was of immediate use, but the United States had virtually no army. Besides the transport of supplies, millions of men had to be conscripted and trained. There were few munition factories. Tanks, guns, and even rifles had to be supplied by the British and French—not the other way around. No American tanks, and hardly any airoplanes, ever reached the American front. Besides raw materials, the main American contribution was manpower—to be used in a land army operation. How were more than 1,000,000 troops to get to Europe in view of the U-boat threat?

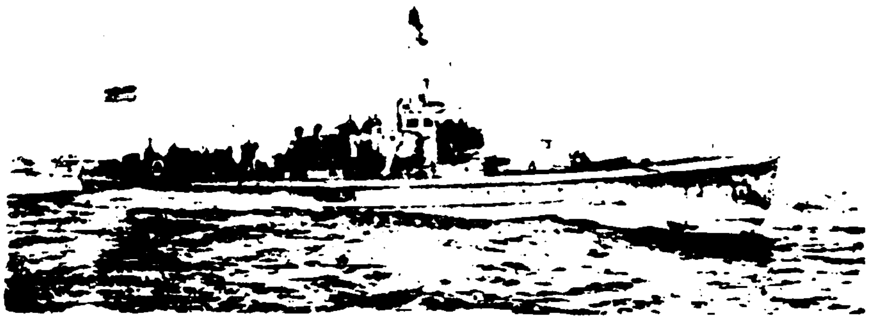
When the concept of the convoys was proposed by US Admiral Sims to stop the U-boat decimation of merchant shipping, the British Navy initially opposed the idea. There were only 200 British destroyers, and half of these were needed with the Grand Fleet, Britain's shield in case the German battleships emerged. Only when 34 American destroyers joined 100 British D.D.'s were area patrols diminished and convoys organized—in May 1917.

Antisubmarine warfare became a major concern of the United States. A major part of U.S. industrial power was allocated to the task of providing shipping and warships to assure the safe transport of manpower and supplies to Europe.

A vast program of building cargo ships from standardized parts was undertaken. The building of major battleships was delayed; the yards turned-to on a program of 258 destroyers and 440 submarine chasers of a new design (see Fig. 1).

On June 1, 1917, scientific representatives from England and France joined their United States' counterparts to discuss acoustic sensors that should be installed on the existing ASW platforms, as well as those under construction. Sir Ernest Rutherford urged the prosecution in listening devices using the binaural effect; while Fabry and Abraham explained the ultrasonic efforts carried on in France by Professor Langevin.[6] As described in Ref. (1), the SC-tube arrangements shown in Fig. 2 were selected because of their operating simplicity.

Captain Leigh of the U.S. Submarine Headquarters, New London, did outstanding work in fitting acoustic sensor systems not only on American ASW vessels, but also on British vessels. He developed



SC 209 Photo Navy Dept. Bureau C. & R.

331 110-FOOT BOATS :—

SC 1-4	SC 143-145	SC 275—301
SC 6	SC 147—159	SC 303—310
SC 17—27	SC 164—169	SC 320—346
SC 34—59	SC 178—186	SC 349
SC 61—64	SC 188—208	SC 351—356
SC 68—74	SC 210—218	SC 405
SC 77—116	SC 220—242	SC 407—409
SC 118—131	SC 244-248	SC 411—441
SC 133—138	SC 250-273	SC 443
		SC 444.

Missing Numbers :—Transferred to French Government—*SC 5*, *SC 7—16*, *SC 28—33*, *SC 65—67*, *SC 75—76*, *SC 140—142*, *SC 146*, *SC 160—163*, *SC 170—177*, *SC 243*, *SC 249*, *SC 313—319*, *SC 347—348*, *SC 350* (all of first contract), *SC 357—404*, *SC 406* (all second contract). Transferred to Cuba: *SC 274*, *302*, *311*, *312* (all first contract). Never built: *SC 139*. Contracts cancelled: *SC 410*, *442*, *445—448* (third contract). War losses: *SC 60*, *117*, *132*, *187*, *209*, *219* (all first contract).

Built 1917-19. *Designed* displacement, 54 tons: *actual* displacement, owing to heavier guns and other alterations, 77 tons *normal*, 85 tons *full load*. Wooden hulls. Length, 105 feet (*p.p.*), 110 feet (*o.a.*). Beam, 14 feet $8\frac{3}{4}$ ins. *Mean* hull draught, 5 feet $5\frac{1}{4}$ ins., *full load* aft, 5 feet $8\frac{1}{4}$ ins. Machinery: three sets of 220 B.H.P. Standard petrol motors = 18 kts. *designed* speed. Owing to added weights, 16·85 kts. is reported to be actual full speed. 2400 gallons petrol = 900 miles at 10 kts. Complement, 27. Have small radius W/T.

Armaments : Designed for 1—6 pdr. and 2 M.G., but these were only mounted in a few boats. Majority have 1—3 inch (23 cal.), 2 Colt M.G. and 1 Y-gun. Some boats have an extra 6 pdr. Carry depth charges.

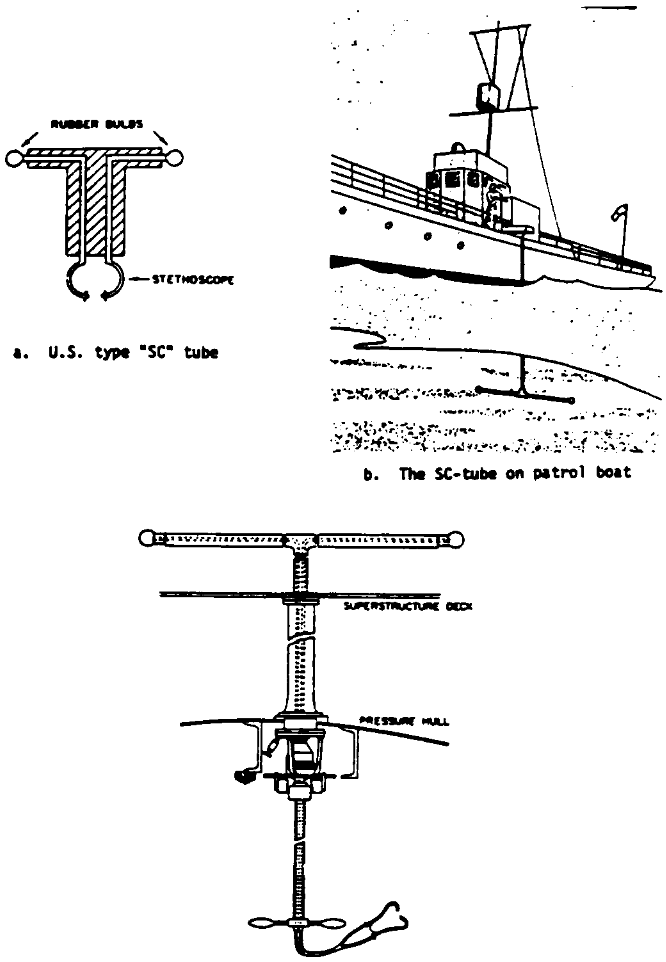
Hydrophone Gear : Boats fitted out in this way have either (*a*) K-tube fish hydrophones of 30 miles acoustic radius, or (*b*) SC and MB hydrophone tubes built into (and insulated from) hull of 3 miles acoustic radius. All boats with hydrophones carry extra load of depth charges. (Note: The K-tube fish hydrophone was a less streamlined version of the OV-tube described in Ref. (1).)

Notes.—Quick rollers with period of about 5 secs. A very full description of these craft was given in the "Journal of the U.S. Naval Institute" in an article contributed by Comm. J. A. Furer, Construction Corps, U.S.N. To this article we are indebted for the majority of foregoing details and following Table.

Fig. 1. Description of submarine chaser of World War I (Source: *Janes' Fighting Ships*, 1961, reprinted by Arco Publishing Co., 1969, p. 225.)

training schools for operators; he also developed the tactics to be used. (Since the equipment provided bearings to target only, three ships were used to localize and attack by cross fixing.[7])

Quantity production was essential since more than 20 surface vessels were required to counter one U-boat. The figure was about 20 to 1 in 1917 and after American production reached the European theatre in 1918, the ratio was about 30 to 1.[8] In order to meet the sensor and weapon needs, the Americans produced more than 3,000 SC-tube listening sets[9] and the British greatly increased their production of depth charges.



a. U.S. type "SC" tube

b. The SC-tube on patrol boat

c. Type SE-4214 (SC) sound receiver as installed on a U.S. submarine

Fig. 2. "SC" tube description and installations—World War I

British Effort 1916–1918[10,11]

Antisubmarine warfare had its beginning on April 23, 1916 when the British trawler "Cherio", using the newly developed sensor-weapon system consiting of a directional hydrophone receiver and depth-charge "bomb", located and sank the German submarine, the UC-3. It was to be at least a year, however, before hydrophones and depth charges were to be available in sufficient numbers to be effective.

The British directional hydrophone, the "Drifter Set" (shown in Fig. 3) gave way to the SC-tube arrangements (shown in Fig. 2) because of the persuasion of and demonstration by the U'S' Captain Leigh, as described above. The binaural SC proved superior to the Drifter Set in finding the submerged submarine and directing the depth-charge attack.

The British were the first to realize the critical nature of the placement of explosive charges near the submarine. The first 120-lb depth charges had to be located within 30 ft. of the pressure hull to destroy the submarine. Obviously, with the crude state of the acoustic art, many charges were needed to

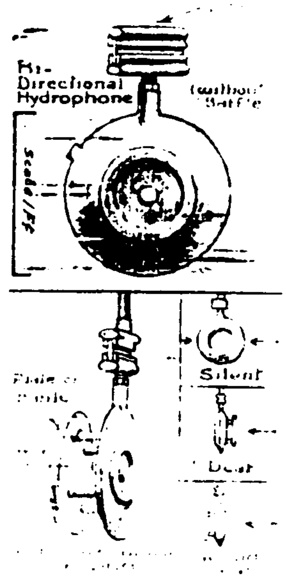


Fig. 3. "Drifter Set," circa 1916. The "baffle" removed target ambiguity. Shown above the hydrophones is a vibration mount probably used to minimize noise conducted down the pipe suspension. (Drawing adapted from W. Bragg, *The World of Sound*, Dover Publications, G. Bell and Sons, 1968.)

be effective. As soon as the need to increase the kill radius was recognized, charges of 300 lb were developed to increase the kill distance to 50 ft. Charges that went off within a few hundred feet could damage a submarine sufficiently to drive it to the surface. Even if a submarine survived a depth-charge attack, the morale of the crew was severely tested.

During the early part of 1917, Great Britain had only from 100 to 200 depth charges available for use per month, whereas in 1918 more than 2,000 charges were expended per month in attacks on U-boats. The weapon looked much like an ash can, contained 300 lbs of TNT, and was detonated by a hydrostatic trigger that was preset to a desired depth. Because these charges could normally only be rolled into the water over the stern, it became evident in 1918 that the pattern could be improved if the charges could be also tossed outboard to the port or starboard. The idea produced the Y-gun on which two ash cans were set on a saddle and fired in an attack pattern with an improved distribution of explosive.

U-Boats Countered But Not Defeated[12]

It should be noted that in 1917 and 1918, the German submarine output more than kept pace at first with their destruction. In 1917, the *net gain* in submarines was about 45, but in 1918 the two exactly balanced (74 added, 74 lost).

The hydrophone-septh-charge combination on ASW vessels, although not too efficient in destroying the enemy, were efficient enough in convoy protection to keep the submarine down to allow the convoy to escape. Although the Germans managed to keep 30 to 40 U-boats at sea to attack convoys, they were less effective going into 1918 because of improved convoy organization and the persistence of the German tactic of operating U-boats independently. Single attacking U-boats could be forced to submerge while the convoy escaped.

The U.S.-Allied ASW effort did not kill very many German submarines. Success was evaluated in terms of ships *not* sunk and of troops and goods delivered. About 183 submarines were destroyed with 162 available at the end of the war. (See Table II.)

TABLE II. German Submarines Lost During World War I
(From data, Ref. (5))

1914	1915	1916	1917	1918 (10 MONTHS)
5	19	22	63	74

SUMMARY OF SUBMARINE WARFARE ACOUSTIC TECHNOLOGY – 1919

As previously described, because of mass production needs, little, if any, sophisticated sonar saw operational use during World War I. Toward the end of the war major interest was demonstrated in improving passive sonar, in silencing ASW platforms, and in developing active sonar.

Passive Sonar—United States

Dr. Harvey Hayes while at the New London Experimental Station pioneered in the study of electrically steered, both hull-mounted and towed passive sonar. In April 1918, he developed an advanced type of system as shown in Fig. 4. The system consisted of 12 hydrophones mounted under protective blisters on each side of the bow and a pair of 40-ft-long "eels" or towed arrays. Each unit contained 12 hydrophones and was towed as shown. Pains were taken to minimize sonar self noise in this system.

Dr. Hayes stressed the utility of having both hull-mounted and towed units operating on the same ship. "This combination is very favorable for searching submarines for the reason that the eels can be used for picking up faint or distant sounds, thereby directing the listening boat to a point where the submarine can be heard and followed by means of the 'on-board' lines. Moreover, the distance of the submarine can be judged with some accuracy by determining its bearing on both the eels and the 'on-board' lines. With the distance between the eels and the blisters known, the range of the submarine can be readily determined by triangulation. While this method does not determine range with sufficient accuracy for bombing purposes, it is sufficiently accurate to be helpful in making an approach."[13]

During the course of his investigations of 1918-1919 Dr. Hayes described problems of propeller, propulsion plant, auxiliary machinery noise, as well as noise caused by the flow. He did not fully understand the mechanisms, but he pioneered in the approach of minimizing sensor self noise to optimize signal-to-noise ratio for the sonar operator. Between 1919-1921, Dr. Hayes' work at the war's end and shortly thereafter was widely published and probably was utilized by the Germans when they started their GHG developments in 1927. It should be noted that after the Sound Division was established at the Naval Research Laboratory in 1923, the reports issued were usually classified, and distribution was limited.

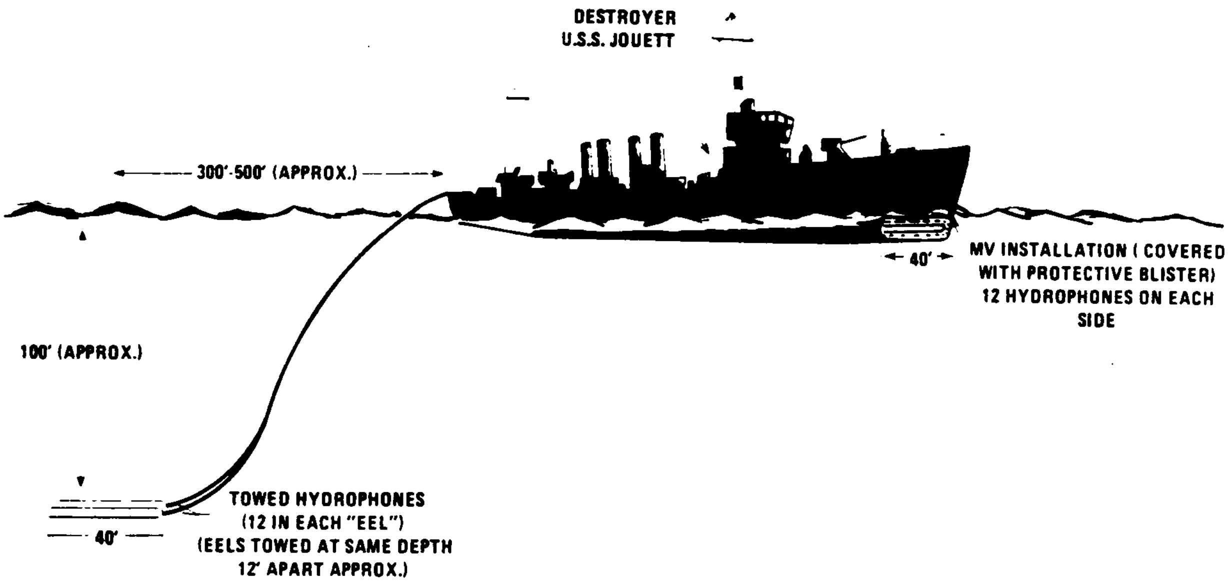


Fig. 4. Experimental passive sonar installation, April 1, 1918, hull-mounted M-V tube installation and towed pair M-V "Eels." Note: Circa 1919—the M-V acoustical system was replaced with the electrical M-V tube. Twelve hydrophones on port side and 12 hydrophones on starboard were used binaurally with electrical delay-line steering. (Adpated from photographs and descriptions, H. C. Hayes, "Detection of Submarines," Proceedings of American Philosophical Society, vol. LIX, no. 1, 1920; and descriptions in G. W. Stewart and R. B. Linday, *Acoustics*, Van Nostrans, 1930, p. 282.

Passive Sonar—United Kingdom

In Britain, A. B. Wood and his associates at the British Admiralty "Board of Inventions and Research" (BIR) starting in 1915, developed fixed, hull-mounted, and towed acoustic sensors (see Fig. 5) that were used for many operational applications. These included harbor defense, ship and submarine sonar for ASW, mine-triggers for ASW, and surprisingly, for *acoustic evaluation of ship and submarine silencing.*

Various hydrophones[14] used during World War I are shown in Fig. 5(a). The Drifter Set with baffle (PDH M 11) and Tandem Directional Hydrophone were developed before America entered the war. The "Ryan Eel," the "Sentry Fish," (shown in the figure) and the "Lancashire Fish Towed Hydrophone" (Fig. 5(b)) were developed later in the war and were used much like the Harvey Tayes Towed Hydrophone Eels described previously.

The attempt to simulate low water noise in towed hydrophone configurations that resembled eels and fishes proliferated in 1917 and 1918. This effort arose after it was noted that when sea lions swam rapidly past a sensitive underwater hydrophone, no sound was heard, although the "water noise" could easily be heard when the animals broke surface. Wood writes, "My own impressions of towed hydrophones in general use at this time was not very favorable. At speeds above 3 or 4 knots extraneous noise due to towing rope vibration, water noise, and own ship's propeller noise tended to mask the 'wanted' noise of a distant ship or submerged submarine, and ranges of detection were rather small. Attempts were made to tow hydrophones from a low-flying seaplane, but the results were not encouraging." As previously described in Ref. (1), the British also tried dropping various types of hydrophone units from blimps to locate recently submerged submarines.

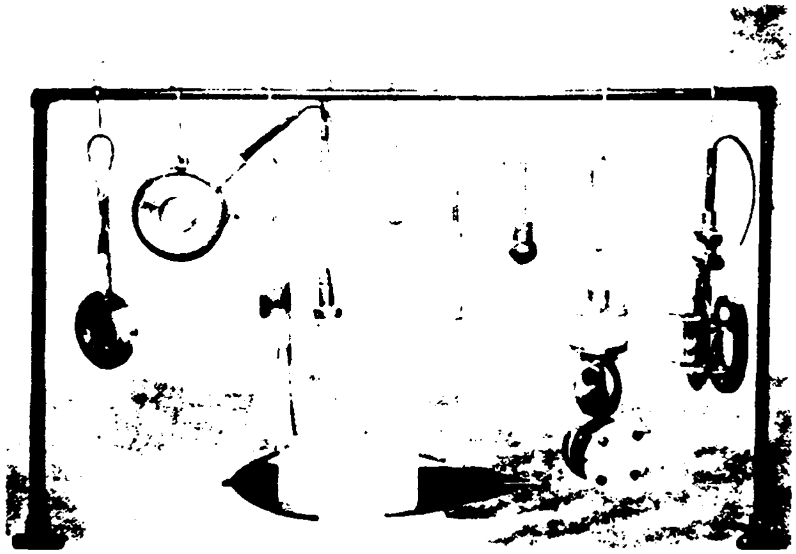


Fig. 5(a). Miscellaneous Hydrophones Circa 1919

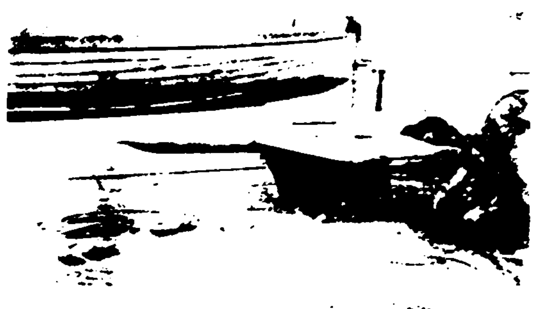


Fig. 5(b). The Lancashire fish towed hydrophone

Fig. 5. United Kingdom-developed hydrophones (1919). During World War I acoustic sensors were developed for sonar, acoustic measurements, and mine warfare. (From A. B. Wood Memorial Issue, Journal of the Royal Naval Scientific Service vol 20, no. 4, July 1965.)

QUIET OPERATIONS OF SUBMARINES

The British submarine navy was very active and innovative during World War I; it passed on a considerable amount of valuable information to the emerging U.S. submarine force. British submarines, having been especially modified for antisubmarine operation, had operated in the Baltic and Black Seas to disrupt enemy shipping. Twelve "R" class boats specifically designed for SSK operation were built during the war. As a result, British acoustic technologic development not only considered antisubmarine, but also pro-submarine applications.

Starting in 1916, the British Admiralty "Board of Inventions and Research" (BIR) developed equipment and techniques to measure the sound output, i.e., the "signatures" of submarines and surface ships.

(At this time no absolute technique existed for measuring sound pressure in dynes/cm^2 or in decibels—the dB had yet to become a guantitative term in acoustics) The measurements disclosed that the cavitating propeller was the loudest component of the operating vessel's sound signature.

On the basis of radiated noise measurements on propellers, J. H. W. Gill at the Admiralty Experimental Station replaced a propeller with a hydraulic jet on a trawler designed for submarine hunting; the trawler achieved speeds up to 9 knots. Although the vessel was considerably quieter than before, the engines and propulsion plant were so bulky that they discouraged further application.[16]

By 1918 German, British, and American submarines adapted their operations to minimize propeller cavitation. Gradually, quieter electric motors and auxiliaries were developed. Near the end of the war both the United Kingdom and the United States were designing and building submarines to operate more quietly when submerged.

In Ref. (16) Admiral Lockwood describes his New London experiences in 1918. "My own operations were concerned mainly with training submarine school personnel and working with subchasers and other antisubmarine patrol boats. They had hydrophones which were intended to detect sounds emanating from submarines; however, to use them the chasers and patrol boats had to stop and drop the instruments over the stern. Meanwhile, we submariners would cut our motors to silent running speed, change course, and slip away. Only one of our would-be killers had an 'asdic'—a British electronic device that sent out a beam, which if it struck a metal hull, returned an answering 'ping'. This we felt held more promise than hydrophones.

Active Sonar Development

The possibilities of quieter submerged submarine targets coupled with own-ship self-noise problems spurred the development of active sonar systems. It was believed that *high* ultrasonic frequency active sonar would optimize target reception because it would enable the concentration of acoustic energy in a beam, which when "illuminating" a target submarine would not only provide target *bearing*, but through simple timing circuits *range*, and because own-ship platform noise is generally mainly low frequency and would interfere with target reception.

If one ship could become an efficient target locator with instantaneous fire-control for weapons, the more than 20:1 ratio of ASW vessels to one submarine could be reduced to more economical proportions.

Langevin's Experiments

After a number of years of support by the French navy, Langevin demonstrated in 1917 that it was possible to beam sound signals at a submerged submarine and to locate the submarine from the echoes.

For his work he used high-power French naval radio-frequency transmitters as well as communication receivers. Instead of driving an antenna in air, he drove a piezo-electric transducer underwater (of the type shown diagrammatically in Fig. 6). The watertight box shown used one electrode of a steel-quartz-steel "sandwich" to couple sound output to the sea. The other electrode was insulated within the box and connected to the radio-frequency circuits. The sandwish assembly was designed to resonate mechanically at 38 kHz. Then when a pulse of radio-frequency energy at this frequency was applied, a maximum response was achieved. The entire assembly radiated like a piston whose dimensions were large compared to a wavelength—a cone of sound of about 20 degrees was generated by this apparatus.

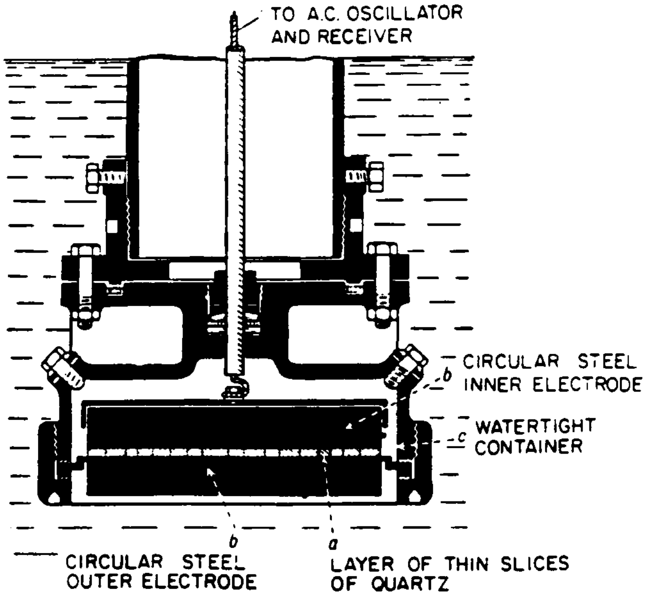


Fig. 6. Langevin quartz ultrasonic transmitter. The steel quartz-steel assembly was designed to resonate mechanically at the radio-frequency of the electronic driver, and to radiate like a piston. The dimensions were large compared to a wavelength so that a cone of sound, about 20 deg at 38 kHz, could be generated. (Adapted from A. B. Wood, *A Textbook of Sound*, MacMillan, 1941, p. 154.)

A switching circuit allowed "ping-listen" operation—a ping was sent out, the switch was thrown to receive and when the echo impinged on the outer diaphragm, rf voltage was generated at the leads. The heterodyne circuits in the communication receiver made the ultrasonic echo audible.

Although improved somewhat (the United States replaced the quartz-steel sandwich with magnetostrictive rods to drive a steel diaphragm), the sonar devices used by the United States and United Kingdom in 1939 were not much different than the device represented in Fig. 6.

British Asdic Beginnings

In 1917 the British took over the conversion of Langevin's device into operational equipment. In his memoirs, Wood described the origin of the term "Asdic" and the development of active sonar in 1917-1918.[17]

"At Parkeston Quay and at Dartmouth the whole process was one of our best kept secrets. It was referred to in conversation and correspondence by the code name 'Asdics'—meaning 'Anti-Submarine Division-ics.' The 'ics' at the end of the code word had the same significance as in words such as physics, statics, dynamics, kinetics, electronics, acrobatics, etc., meaning 'pertaining to,' the initial syllable(s) of such words usually being abbreviations. No reference to quartz was permitted, the code name being in this case 'ASDIVITE,' the 'A.S.D.' referring to anti-submarine division, as before. When experience had been gained with 'outboard' experimental equipment, the 'Asdic' transmitter was eventually mounted in a dome or in a streamline case, let down through the bottom of the ship. In this way it was always surrounded by still water at all speeds of the ship. A controlling device was fitted by

means of which the Asdic could be turned through any horizontal angle and also could be given a variable vertical tilt. Range and bearing observations on surface ships gave good results. The sea trials of Asdic equipment were carried out mainly from the barge on the River Stour and from the drifter 'Hiedra,' with occasional trips to sea in ships of the Harwich Flotilla, such as H.M.S. 'Melampus.' On a surface ship of 700 tons, stern-on, a range of 1,400 yd was obtained with very accurate direction. With a large submarine the maximum range 'surfaced' would be about the same, rather than when submerged. During the last four months of the war the Asdic section of Parkeston Quay was transferred to the Dartmouth sub-station, as I explained earlier. At the end of the war Asdics was coming into its own. The experimental period was just reaching the ship-fitting and development stage when the war ended."

UNDERSEA WARFARE PLANNING 1919-1939

Table III shows the fleets of the principal powers between 1919 and 1939. Figure 7 shows the naval expenditures of the United States and the United Kingdom over the same interval; Fig. 8 is an overview of historical events relative to submarine warfare planning that interrelated with the above, and summarizes material to be covered in this review.

As shown in Table III, the United Kingdom was the unquestioned naval power of the world in 1919; by 1939 her position had severely eroded. Similarly, considering the United States' two-ocean responsibilities, the U.S. Navy in 1939 was not overpowering in size or capability. For both Britain and America, the curtailing of expenditures (Fig. 7) in the 1920's and the continuation of this curtailment, mainly because of the effects of the Great Depression in the 1930's, severely cut back naval capability.

Political Background—United States and Japan[18,19]

America, led by Wilson, entered World War I to end future wars and to spread the democratic system throughout the world. The petty self-interest and narrow points of view expressed by Allied "statesmen" at Versailles produced a feeling of disgust and disillusionment in the United States. Membership in the League of Nations was rejected; President Wilson prophesied on 4 September 1919 that the League "is the only conceivable arrangement which will prevent us sending men abroad very soon...the only thing that can prevent the recurrence of this dreadful catastrophe." The warning went unheeded. Harding was elected as president in 1920 on a platform of "return to normalcy."

However, the same individuals in Congress who were most determined to remain isolated from the affairs of Europe were most eager for the United States to restrict Japanese expansion in the Orient at the expense of China. Galling to the United States was the British support of Japan, especially with regard to the mandating of former German island possessions to the Japanese. The strategic Pacific island of Yap became a source of controversy after the war. The distrust that showed itself in American protests over this mandate was borne out by the race toward armaments—the United States, Great Britain and Japan had developed ambitious programs for battleship construction and by 1921 much talk circulated about a coming war in the Pacific. Yet a new war was not what the American public wanted. Led by Senator William E. Borah and Secretary of State Hughes the Washington Naval Conference was called in the fall of 1921. Various agreements emerged from this conference—the Nine-Power Pact guaranteeing the "sovereignty, the independence, the territorial, and administrative integrity of China," and the Five-Power Pact controlling the construction of capital ships. It was agreed that the United States, Britain, Japan, France and Italy would begin a 10-year naval construction moratorium, during which no new capital ships (of 10,000 or more tons) would be built. The size of the navies was fixed according to the following formula: 5 for the United States, 5 for the United Kingdom, 3 for Japan, 1.67 for France, and 1.67 for Italy. Having, as they fondly thought, started the ball rolling toward universal peace, the British and American people allowed their armed forces to drift into obsolescence. For about

TABLE III. Fleets of Principal Powers—1919 and 1939

SHIP CLASS	U.K.		U.S.		JAPAN		FRANCE		ITALY		GERMANY	
	1919	1939	1919	1939	1919	1939	1919	1939	1919	1939	1919	1939
Battleships	61	12	39	15	13	9	20	5	14	4	40	5
Cruisers (All Types)	129	65	35	32	33	39	29	18	17	21	40	6
Destroyers	443	159	131	209	67	84	91	58	44	48	200	17
Submarines	147	54	86	87	16	58	63	76	78	104	162	57
Aircraft Carriers + Seaplane Tenders	4	9	0	5	0	8	0	2	0	0	0	0

(Adapted from S. Roskill, *Navy Policy Between the Wars*, (Walker 1968), pp. 71 and 577.)

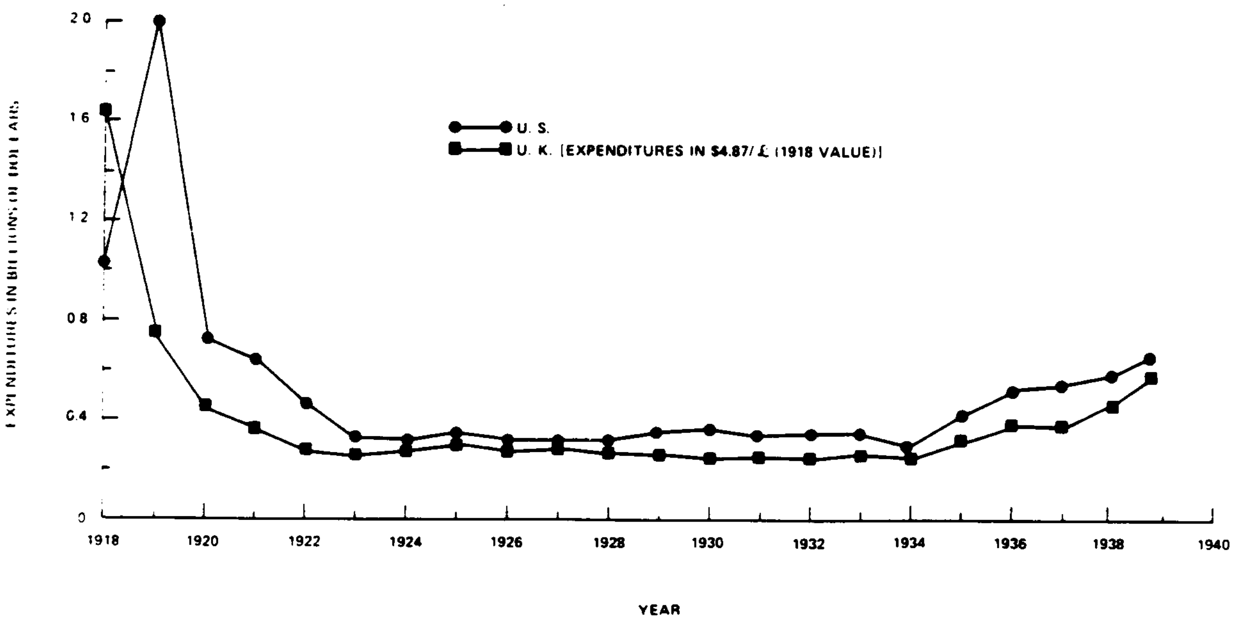


Fig. 7. U.S. and U.K. Navy Expenditures—1918-1939. (Adapted from S. Roskill, *Navy Policy Between the Wars*, Walker, 1968, appendix B.)

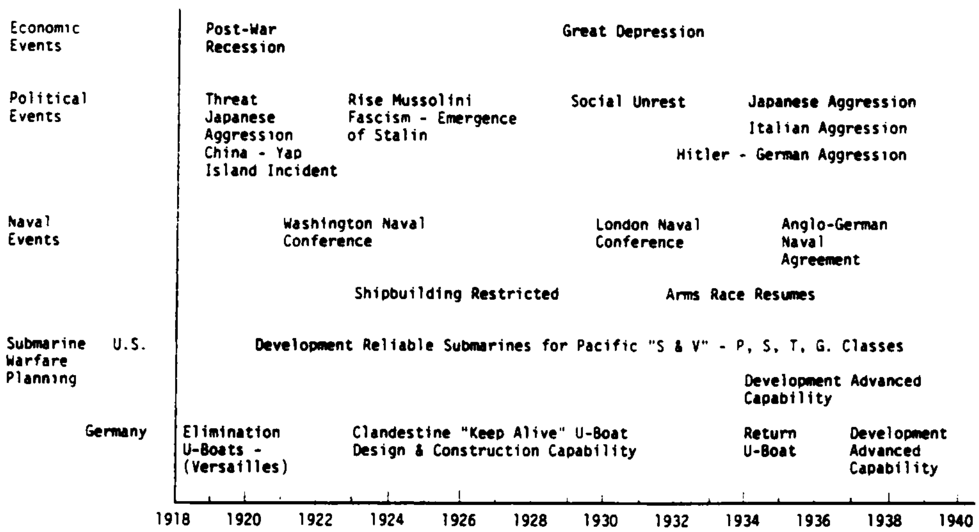


Fig. 8. Overview of events relative to submarine warfare planning—1919-1939

10 years this hardly mattered, but in the 1030's, a time that pacifist propaganda in the United States and the United Kingdom was very powerful, the German, Italian, and Japanese governments started aggressive planning for war. If "England slept," America not only slept, but snored.[20] The Army was neglected as much as the Navy.

Several factors, as shown in Fig. 8, besides a general revulsion against war and aversion from Europe, contributed to this lamentable state of affairs. The recession of 1921-1922 and the Great Depression of 1929-1933 made Congress unwilling to vote money for armaments. By 1932, some 12 to 15 million Americans were out of work; when Roosevelt became president the National government took over the obligations of alleviating economic hardship.

While America was preoccupied with economic problems Japan struck in the Far East. By 1932, Japanese armies crushed all Chinese resistance in Manchuria. This proved to be the first of a series of aggressions that went on without hindrance from 1931 to 1939.

U.S. Submarine Force Development[21,22]

The Japanese threat transformed the submarine service between the first and second World Wars from an inefficient coast defense force to an efficient oceanic attack force. With a forward main base in Hawaii and an advanced base in the Philippine Islands, the United States was strategically well situated; however, it was recognized that the latter would be a prime target of Japanese attack in case of war. The distances in the Pacific are vast—a large, built-in radius of operation was an essential requirement of all warships.

Under the terms of the 1930 *London Naval Treaty* (see Fig. 8) the United States, the United Kingdom and Japan were limited to a total of 52,700 tons for submarines. At this time the United States possessed 81,039 tons plus 10,170 tons building, so that it was necessary to dispose of 38,509 tons. Undersea cruiser sized submarines were abandoned. *It became vital to minimize size and maximize capability.*

To further this end, a diesel development program was sponsored and the Navy reduced weight significantly by adopting a fast-running unit. This prompted selection of electric drive, especially as two units were required for each to achieve required power. Reliable *American* engines became a reality in 1933. In the same year, the first all-welded U.S. subs, the V8 and V9, were launched. Welding saved weight for a stronger pressure hull, enabled fuel oil to be carried in external tanks without the risk of leakage, and speededsproduction with greater economy of manpower. Another feature started at this time was the shock-isolation and shock-mounting of selected pieces of auxiliary equipment. Extra effort was expended to ensure that the equipment mountings would withstand comparable forces as the pressure hull. Attempts were also made to provide sound isolation in conjunction with the above mounts.

As part of the "system approach," U.S. designers, envisaging long-duration operating away from home ports, stressed improved habitability on ships of the U.S. Fleet. Airconditioning was introduced to enable crews to operate efficiently in the Far East where conditions were most arduous.

The Treaty of London limitations stimulated the Naval designer to reduce the size and bulk of the big fleet submarines of the 1920's (e.g., V-class) into more compact, more efficient submarines of the 1930's.

By the mid-1930's, the combination of Roosevelt's "pump-priming" economics and national defense needs raised the funds to build 40 new submarines (the P-S-T-G boats). (As per the Treaty of

London, the new construction replaced World War I vintage construction.) By this time the U.S. submarine force had proven diesels, efficient periscopes, and were practicing tactics later used in World War II. Admiral Lockwood reported[22] that in 1935 a major project was obtaining the range from a sub to a target with the use of sound-bearing information only without having to expose periscope. The submarine force practice-fired torpedoes by means of a newly developed tactical data computer with inputs of *sound* bearings, periscope sightings, and range. In the planning stage was the coordinated attack method—a type of wolf-pack operation in which a whole division of submarines would attack a fleet formation or a convoy.

In 1936, Lockwood describes U.S. Naval exercises of subs with sonar equipped destroyers. At this time U.S. submarines were equipped with false target lures—a device which, after ejection in a cannister through a signal tube, emitted a cloud of gas bubbles to return echoes while the submarine escaped behind the screen. (This technique was also employed by the Germans in World War II.)

When the TAMBOR, the first of the ultimate fleet-types of World War II, went to sea in late 1939, she carried 10 torpedo tubes, 24 torpedoes, a 5-in. gun, a 40-ft attack periscope, a "TDC" fire-control system, JK and QC sonar (to be described later), and had range to operate anywhere in the Pacific Ocean. In addition, she had a speed of 21 knots on the surface, was capable of 10 knots submerged, and she could dive in 55 seconds or less. *This development was a major Naval accomplishment between the wars.* A comparison of typical U.S. and German submarines is given in Table IV. The U.S. Fleet-type was developed for the long distances of the Pacific; the German VIIC was developed for the closer-in operations of the Atlantic.

Political Background—U.K. Economic Problems

Great Britain found herself in an immediate economic crisis after the war. Much of her merchant fleet had been lost to the U-boats: she had loaned large sums of money to her allies who were unable to pay the interest much less the principal. In 1921, two million Britons were unemployed, and other millions were living on the edge of need. Ten years later the effects of the Great Depression had only intensified England's social problems.

Starting in 1929, as a result of the depression, the National Party (union of Conservatives and Laborites) ruled Britain. The new party attempted to deal with the depression by cutting back on government spending, abandoning the gold standard and free trade and reorganizing industry. However, it wasn't until Britain began to rearm that she began to come out of the depression.

The Threat—U.K. View

British naval planning in the 1930's did not take into account a resumption of the submarine warfare attacks of World War I. Stephen Roskill describes the British navy's views on this subject as downgrading the submarine. In Admiralty planning, the advent of improved aircraft and improved Asdic restricted submarine capability. The submarine role in their view was confined to be tactical adjuncts of the surface naval forces. Even when the U-boat building was granted by the Anglo-German Naval Agreement of 1935, no threat to merchant commerce shipping was foreseen. Roskill states that in the British Navy "not one exercise in the protection of slow mercantile convoy against submarines took place between 1919 and 1939."[23]

In the mid and late 1930's, Britain's limited funds for armament emphasized the modernization of her air force and land army to counter Nazi activity. The navy, with limited funds available, assigned top priority to the development of *armored* aircraft carriers to withstand bombing attacks from the air. Attack was considered likely by enemy air forces not by enemy submarines. Limited funding led the Admiralty to build super-destroyers (destroyer of destroyers) of the Tribal class with emphasis on

TABLE IV. Comparison of Characteristics—Typical German and U.S. World War II Submarines

CHARACTERISTIC	U.S. FLEET TYPE[a]	GERMAN TYPE V11C[b]
Surface Displacement	1,525 tons	720 tons
Length	3311 feet	220 feet
Surface Speed (1 Hour Maximum)	20 knots	17.7 knots
Submerged Speed (1 Hour Maximum)	9 knots	7.6 knots
Cruising Radius	15,000 miles	9,700 miles
Engines, Diesel	4 of 1500 hp each	2 of 1600 hp each
Type	2 cycle	4 cycle
Torpedo Tubes:		
Forward	6	4
Aft	4	1
Total Torpedoes Carried	24	14
Guns	1-5 inch + AA	1 37 mm AA 2 twin 20 mm AA 20 mm AA
Crew	85 to 100 officers and enlisted men	44 officers and enlisted men

[a]By the Treaty of London,in 1930, the United States—together with the United Kingdom and Japan—were limited to a total tonnage of 52,700 tons for submarines, none of which could exceed 2,000 tons in surface trim or carry a gun larger than 5.1-in caliber. The age limit of submarines was fixed at 13 years.

[b]Following the unchecked repudiation of the Versailles Treaty in 1935, the Anglo-German Naval Agreement was signed whereby the naval forces of the latter were limited to 35 percent of British total tonnage except for the submarine category. For submarines Germany claimed parity but expressed their intention not to exceed 45 percent of British tonnage—45 percent of 52,700 tons—23,715 tons. Partly because Doenitz preferred many small submarines rather than fewer larger boats, and partly because of the Treaty limitations, the German Type VII was built starting in 1935. If Hitler chose, Germany could have mass-produced the VII in 1938.

(Source—J.A. Furer, R. Adm., U.S.N. (Ret), "Submarine," Encyclopedia Americana (1956), p. 771; and H.T. Lenton, *American Submarines*, (Doubleday, 1973).)

quality and capability rather than numbers. The funds spent on 16 large destroyers could probably have been better spent building more of the smaller, simpler, and standard types.[24] In 1939, Britain was poorly prepared for the ensuing submarine war . . . a saving factor was that the German navy was poorly prepared as well.

German Evasion of Treaty Limitations[23]

In 1937, 4 years after Hitler seized power, the German Admiralty published a detailed and self-congratulatory account of the measures adopted to evade the limitations of the peace treaty. From the time of surrender in 1918, the German navy plotted to keep their capability in the design and building of U-boats and the training of their personnel. In 1920, seven railway loads of rangefinder equipment were removed from the Zeiss factory at Jena and were smuggled into Holland to be stored in the Zeiss branch at Venloo. Similarly, arms of war were smuggled to the firm of Daug in Copenhagen to be sold to Finland, Sweden, and China. The equipment and ordnance smuggled out and sold were used to supply the German Navy's "black funds" which were used to finance illegal forbidden measures.

In 1922, a cover corporation in Holland, IvS Ltd., was staffed by a German naval construction group (formerly at Kiel) to continue and extend their capability in U-boat construction. Through dummy corporations in Germany, submarine designs were prepared for sale to foreign governments. Admiral Raeder became head of the German navy in 1928 and accelerated this activity. By 1930, advanced modern submarines were constructed abroad (in Spain and Finland), thoroughly checked out by German naval personnel in civilian garb, and then delivered to the purchasers.

Rebirth of German Submarine Force[25]

By 1935, the Anglo-German Naval Agreement allowed Germany to rebuild her navy to 45 percent British tonnage, 23,715 tons, and allowed the rebirth of the German submarine force. Admiral Raeder appointed Admiral (then Captain) Karl Doenitz to take charge of the reborn U-boat Fleet.

Doenitz indicates that a motive behind the British allowing the re-creation of the U-boat arm was their confidence in the Asdic. After World War I, the British (according to Doenitz) published a great deal about detecting submerged submarines by acoustic techniques which they claimed could locate and pinpoint the position of the submarine at many thousands of yards.

The German Navy had stockpiled unassembled sections of submarines. By 1936, 18 submarines (750 tons or less) were launched and intensive training of crews had begun. Doenitz established the following training doctrine:

- ignore Asdic publicity,
- fire torpedoes at ranges not more than 600 yd,
- practice coordinated mass U-boat operations,
- practice surface attacks at night, and
- practice evasion of active sonar attack while submerged.

Much of the pre-war German activity in pro-submarine training in the Atlantic paralleled U.S. submarine training effort in the Pacific. Because of the Anglo-German tonnage limitations, the Germans (like the Americans after the Treaty of London) opted for the smallest tonnage boat that could meet operational requirements.

SONAR DEVELOPMENT AND USE 1919-1939

German GHG

In his lectures at the Navy Underwater Sound Laboratory on 7-8 October 1965, Dr. Heinrich Maass of Atlas-Werke, Bremen, one of the pioneers of sonar development in Germany, indicated that little underwater acoustic work was accomplished in Germany during World War I, and the beginnings of passive sonar started in 1925 when the German navy began building the small fleet allowed it by the Treaty of Versailles. Under this treaty, Germany was not allowed to build submarines or to possess combat airplanes. The maximum tonnage allowed battleships was 10,000 tons. The first ships that were built had to operate without protection of aircraft or escort destroyers. Passive listening equipment "had to be of the best to give them the only protection that could be derived other than own ship's artillery." (This included the long-range detection and classification of enemy targets as well as torpedo detection and avoidance.) Before these ships were built a special research and development facility was set up at Kiel where measurements were made of radiated noise and, presumably, of platform and self noise as well. Figure 9 shows a typical measurement made of the freighter FREIBURG on the fixed range at Kiel. Special attention was given to the identification of bow wave noise, machinery noise, and the characteristics of propeller noise. The location of the passive sonar was chosen so that the interference to the hull-mounted sonar would be minimal. In the late 1920's, 12, then 24 hydrophones were mounted on the bows of surface ships in an arrangement called the GHG or *Gruppen Horch Gerät.*

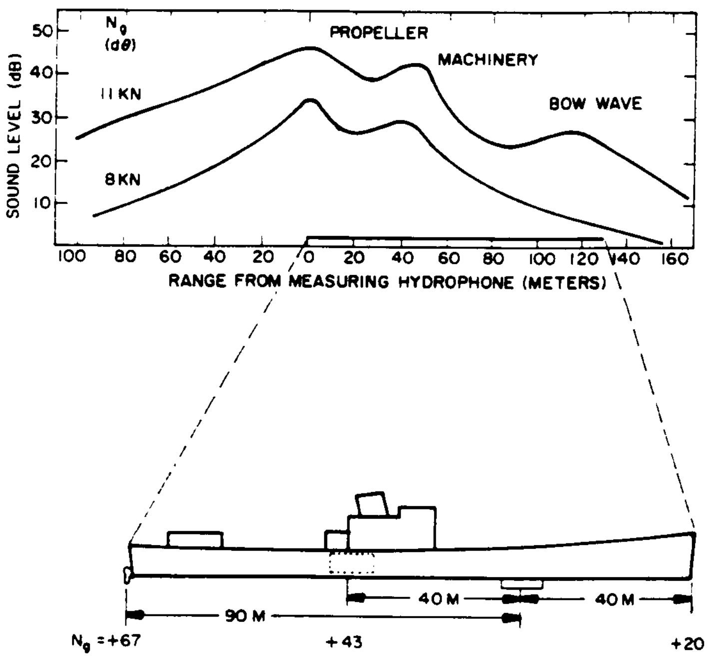


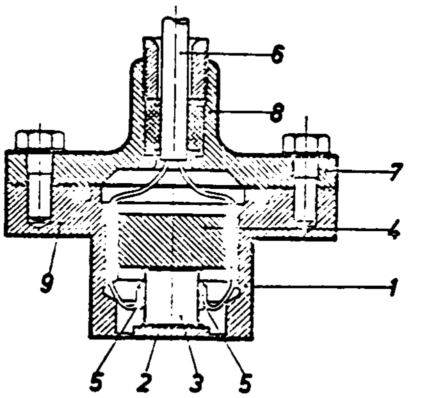
Fig. 9. Broadband radiated noise of Freighter FREIBURG at 8 and 11 knots with indication of Ship-Noise sources as a function of location. (Adapted from NUSC Publication No. NL-3004.)

The GHG configuration evolved with the close cooperation of the naval ship designers and the sonar engineers. The array location was chosen as a cooperative effort and structure near the bow was modified to accept the flush mounted hydrophones of Fig. 10(a) that were vibration-isolated from the hull. Figure 10(b) shows a simplified hydrophone array mounting arrangement made on the PRINZ EUGEN, circa 1938. The broadside view is presented in the upper half of the figure and the vertical projection on the horizontal plane is indicated in the lower part of the figure. The array was elliptical in shape: better bearing capability was provided broadside than forward. The hydrophone array was trained through an electrical delay-line arrangement as shown in Fig. 11. The output of the training unit went through a four-stage amplifier with high-pass filters at 500, 1,000, 3,000, 6,000, and 10,000 cps. The GHG system was modified for submarine application after the Anglo-German agreement allowed Germany to start building submarines in 1935.

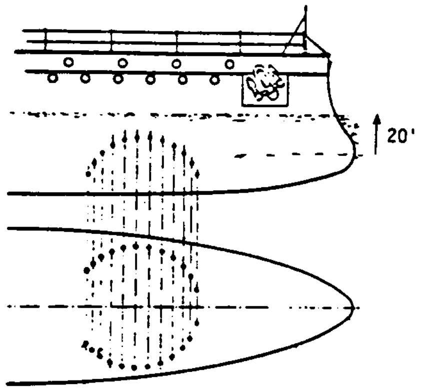
There was no doubt that during the war the Germans excelled in passive sonar, whereas the British and Americans excelled in active sonar.

American JK-QC

During World War I, the American Navy's "in-house" passive listening expert was Dr. Harvey Hayes. His efforts at developing passive sonar for surface ship use against submerged submarines were abandoned by the United States after the war; it reappeared later in the German GHG. He headed-up the Acoustics Division at NRL when it was established in 1923 (the Admiralty Research Laboratory was established in Britain in 1921), and one of his first major endeavors was to enable the Americans to catch up with British and French capability to determine both range and bearing with echo-ranging sonar. By 1927, the group of five—Hayes, Stephenson, Dudley, Struthers, and Klein "constituted the Navy's sole in-house capability and competence to perform research and development in the field of underwater acoustics. It was the responsibility of this group to see to it that the most effective underwater communication and detection equipment was available to the Fleet. Moreover, the Government's ability as a sophisticated buyer in the field of R&D work from private enterprise depended entirely upon this small group. . . ."[26]



(a) Cross Section of GHG Hydrophone. The assembly was carefully vibration isolated and flush mounted to hull with close tolerances. The crystal receiver (3) was of Rochelle salt crystals.



(b) Simplified Receiving Array. The horizontal projection of the array was in the shape of an ellipse. The PRINZ EUGEN had 60 GHG hydrophones on either side.

Fig. 10. Hydrophone mounting arrangement on the PRINZ EUGEN, circa 1938. (Adapted from NUSC Publication No. NL-3004.)

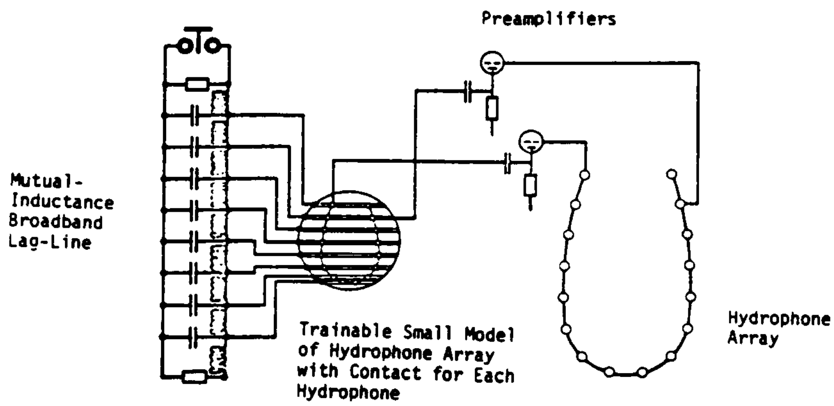


Fig. 11. Training unit for GHG configuration, circa 1935. The output of the broadband lag-line went through a four-stage output amplifier with filters. (Adapted from NUSC Publication No. NL-3004 and L.E. Holt, "The German Use of Sonic Listening," JASA vol. 19, no. 4, July 1947.)

This small group slowly increased in numbers and responsibility. The building program of U.S. destroyers (97) and U.S. submarines (45) in the 1930's allowed the NRL Sound Division to build, test, and check out prototype sonar equipment suitable for the new Fleet platforms. By 1934, industry delivered the first production version of the QC equipment (active sonar) which went on surface ships, as well as modified JK and QC gear that went on submarines (see Figs. 12 and 13).

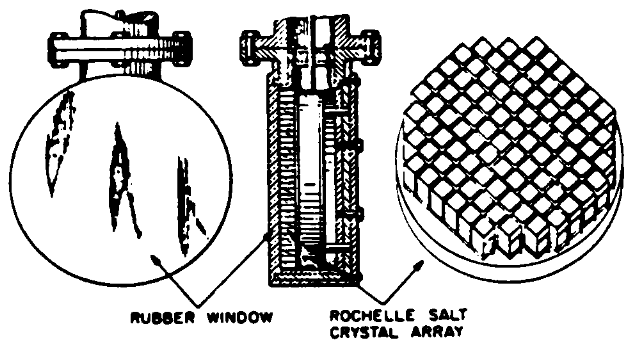
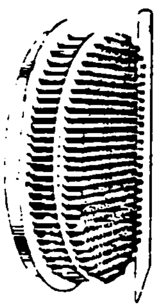


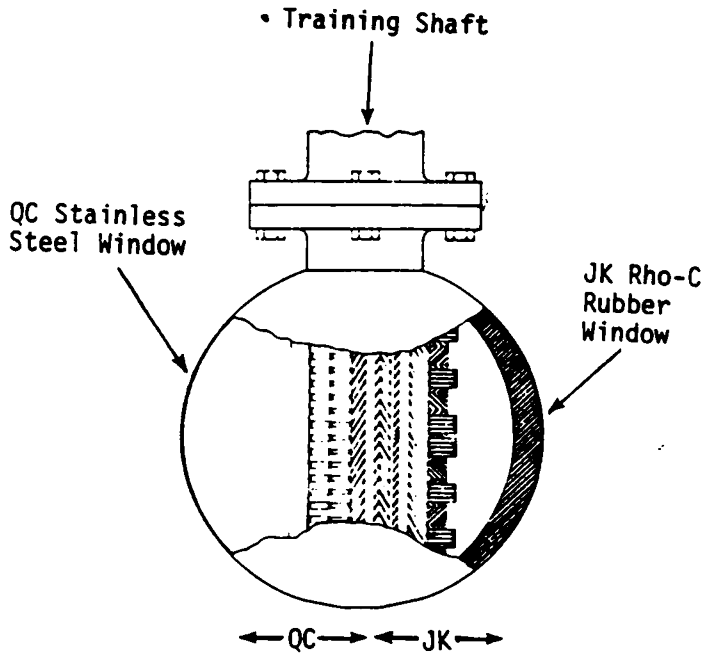
Fig. 12. JK receiving head. The JK was used on submarines as a passive receiver in the 1930's. It replaced the SC of World War I. The diameter of the Rochelle salt crystal array was 15 in. (Adapted from E. Klein, "Notes on Underwater Sound Research and Applications before 1939," ONR Report ACR-135, Sept. 1967.)

On the submarine the JK (passive sonar) was used to find and classify targets at long ranges, then when the sub closed for attack, the QC was used in a single-ping mode to obtain range and bearing for torpedo attack. (A single ping was considered as being unlikely to alert the enemy to the submarine's presence.)

On the surface ship the QC was used as a continuous ping screening sonar. Presumably, the submarine could hear the surface ship fleet units at ranges greater than those the QC could reach. The submarine had to be detected and classified, usually by other than acoustic means, e.g., by sighting when on the surface or sighting torpedo wake when submerged. If alerted, the QC could operate more efficiently. A factor of its operation was the time required for a 360-deg search. Each ping could cover 20 deg per transmission. At ranges of 3,000 yd, a complete search around the ship required about 4 min.



(a) Magnetrostrictive tube array (QC) with its backing plate. This particular assembly was built by the Submarine Signal Co. and was composed of about 600 tubes fastened to the plate. The QC was used as an active sonar on surface ships in the 1930's.



(b) Combination of two projectors, on the right is a Rochelle salt (JK) listening device with castor oil and the spherical rubber (Rho-C) window; on the left is a magnetostriction transducer (QC) with ethylene glycol-distilled water in front of the radiating plate and a thin stainless steel window. The assembly above was used on submarines in the 1930's. Targets were detected and classified on the JK and then the QC was used in a single ping made for range.

Fig. 13. QC-JK Transducers. (Adapted from E. Klein. "Notes on Underwater Sound Research and Applications before 1939," ONR Report ACR-135, Sept. 1967.)

American Fleet Tactics and Training[27]

The state-of-the-art of Fleet operation is described in a report to ComDesDiv 60 for the period September to December 1935:

"At present no dependence whatsoever can be placed upon defense sound screening as a guarantee of reasonable protection of the Fleet. A cleverly handled submarine has two chances out of three to get through. On the other hand, once the submarine's presence and location are known, time permitting, here ultimate destruction can be made fairly certain. In training problems aircraft made a high percentage of sight contacts with submarines ahead of the Fleet. The 'Offensive Sound Screen' tests show that sound-equipped destroyers could have exploited these contacts with 87-1/2 percent chance of destroying in 1-1/2 hours all submarines within six miles of them."

The foregoing naval operational report shows that at the beginning of 1936, ASW equipment and tactics were in the form they were employed in World War II. As a result of this report, Destroyer Division Nineteen was ordered to operate with Fleet-type submarines from 1936 to 1939 to improve both anti- and pro-submarine capability. By 1939, the continuous testing of underwater sound equipment under service conditions had resulted in changes to ruggedize equipment and to improve displays. The

role of the efficient sonar operators became recognized as did the fact that sonar training had to be standardized. Gradually the elements of the training program were combined into the Fleet Sound Schools at San Diego and Key West in 1939.

Sonar Refraction Effects–The Bathythermograph

In 1939, Fleet operation with the modified QC had resulted in improved capability—the original 800-yd single range scale was replaced with a dual-range scale of 1,000 and 5,000 yd.[28] However, operations in deep water (off Guantanamo Bay and San Diego) showed that, under certain conditions of sound velocity gradient, the sound cone emitted from the transducer might be bent back to the surface or, under other conditions, bent down into the depths—the "searchlight" beam was very dependent on the characteristics of the ocean between source and target.

After an extensive series of tests, NRL and the Woods Hole Oceanographic Institute combined to develop a Navy version of an instrument called the Bathythermograph or "BT." This equipment gave the operator a measurement of the temperature as a function of depth near and around his ship. From various types of temperature profiles nomographs were furnished as to the path of the sound beam. A towable version of the BT was developed for surface ships and a hull-mounted BT was devised for submarines. In this way, the U.S. forces used environmental information to assess sound propagation conditions—a vital input for tactical decision making.[29]

Comparison of U.S. and U.K. Sonar Developments—1939

The American and British scientific collaboration in ASW acoustics stopped shortly after 1919. Acoustic developments proceeded independently, largely at the Admiralty Research Laboratory and the Naval Research Laboratory.

It was quite striking that when information exchange began in 1939 that both nations had paralleled developments in the field of echo-ranging sonar, and possessed very similar fleet equipment. The primary differences were:

- British Asdic transducers were of quartz-steel, whereas the U.S. sonar used magnetostrictive rods driving a steel plate.
- British Asdic domes were streamlined, while the U.S. domes were spherical.
- American bathythermograph equipment was more satisfactory than the British to determine "range of day" sonar capabilities.

Another difference was that American tactics were developed mainly for Fleet action in the Pacific; British exercises emphasized Fleet action in the Atlantic and Mediterranean. Neither navy had done much (if anything) to consider the problem of protecting convoys of merchant ships against an improved generation of submarines—boats that could travel at higher speeds and with stronger hulls, dive deeper.

Both navies had done little to improve the weapon used to attack and destroy submerged submarines—the depth charge. The only difference on the stern of the 1918 and 1939 U.S. and U.K. ASW destroyer was the size of the "ashcan"—the newer version carried 700 lb of explosive as compared with 300 lb of TNT in 1918.

U.S. Evaluation of GHG on Prinz Eugen[30]

As stated previously, the GHG configuration evolved as a result of close cooperation of the naval ship designers and sonar engineers. Such cooperation did not exist in the United States or United Kingdom. Sonar sensors were "add-ons" usually after the ship was constructed and accepted by the Navy.

The U.S. equipments on submarines tended to retain the through-the-hull mechanical train arrangements (see Fig. 2c), and simply replace the receiver assembly—e.g., the JK replacing the SC tubes. Electrical steering pioneered by the United States in 1918 was adapted by the Germans in the GHG, with provisions to minimize sonar self noise.

Doctor Guy Harris of USNSL rode the PRINZ EUGEN in 1946. In introducing Dr. Maas at the USNSL meeting previously described, he discussed his own experience with the German GHG on the PRINZ EUGEN.

"We rode the PRINZ EUGEN down the east coast to Panama, and on the way down we found that we could do things with that listening equipment that were unheard of in our experience; so one of the U.S. officers aboard the PRINZ EUGEN flew back to Washington immediately as we touched base in Panama. He went to the CNO and got special permission to carry on some exercises on the west side, that is, on the Pacific side of the Canal. Immediately, some exercises were set up with American submarines (we had a squadron based at Panama in those days) to fire U.S. torpedoes, both steam and electric, and the PRINZ EUGEN would try to detect and evade. Now, on the way down to Panama the German crew was still aboard, that is, part of the German crew and the German captain In discussing this equipment, the Captain made a statement that is rather important. He said that when the PRINZ EUGEN was operating in the North Sea around the Orkneys and south of Iceland, some 200 British torpedoes were fired at it, but that the ship suffered only one hit in all that time, and that was in the rudder, aft of the screws. They rigged a jury rudder and got into Wilhelmshaven safely. . . .

"The torpedo fitting exercises at Panama were most successful. Because we detected every American torpedo that was fired, both electric and steam, usually at the point of leaving the tube, we were able to avoid and evade each one of them so they went down either to the right or left. The ship was extremely maneuverable and had a wonderful system for working out torpedo evasion using the passive information. This is a big story in itself. I cannot take the time to tell the tactical situation. . . .

"There is another very interesting thing in connection with this kind of passive detection equipment. . . .In 1941, the HOOD, the superdreadnaught, the pride of the British Navy, the greatest man-of-war afloat, was operating around Iceland. The BISMARCK and the PRINZ EUGEN, in company, detected the HOOD across and below the horizon, some 20 miles away. They tracked the HOOD for a long way. Then she suddenly boiled over the horizon and a running fight occurred; a lucky shot (many shots were fired) went down the main stack into the main ammunition center of the HOOD; the HOOD blew apart. That was the end of the greatest superdreadnaught that has ever been built. What part did this passive detection equipment play in that battle? According to the people on the PRINZ EUGEN with whom I discussed this episode, *they had tracked the HOOD over the horizon on their passive equipment 20 miles away* for a long distance and had good range bearing course on it.[31] When the decision was made, they turned into the HOOD and went into the battle with the fire control situation all set up. Now, in the history books, the credit is given to the BISMARCK for firing the lucky shot. The people on the PRINZ EUGEN were certain that they were the ones that fired the lucky shot. At any rate, this passive sonar played a very important fundamental part in one of the greatest sea battles of all time."

The ability of U-boats to exploit this type passive sonar provided as important tactical advantage over forces wedded to active sonar. Passive sonar provides important classification information unavailable to active sonar. It provides longer range detection capability. It provides torpedo warning and evasion capability, especially when transient signal noise attendant to weapon preparation and firing is considered. The German capability of using the same electronics and sensors on surface ships and submarines provides major savings in cost (mass production, common training, maintenance,

etc.), which has not been duplicated elsewhere. Passive sonar developments for surface ships are still today (1974) struggling for acceptance.

ORDER OF BATTLE—SEPTEMBER 1939[32]

At the start of World War II, England had only about 220 Asdic-fitted anti-submarine craft consisting of approximately 165 destroyers, 35 patrol craft (i.e., sloops, frigates, corvettes), and 20 trawlers. This total may be compared with the more than 3,000 ships (about 450 destroyers, 170 patrol craft, and the remainder trawlers and small craft) available to the Allies for antisubmarine warfare in 1918.

The British, profiting from their experience in World War I, had learned that the ocean convoy system did more than anything else to reduce shipping losses. They knew that the convoy system works best in open water where evasion can be employed and that its success depends upon efficient escorts armed with effective offensive weapons. They were also aware of the fact that an efficient U-boat tracking system is necessary to practice effective evasion, and a daily U-boat plot based on contacts, DF fixes, and intelligence was used throughout the war.

Meanwhile, the U-boats available to the Germans at the start of World War II were faster than those used in World War I and were also considerably stronger; they were able to dive deeper and to withstand more depth-charge punishment. The Germans had also developed an electric torpedo which left no visible actions at sea; active sonar was used by the escorts after the U-boat disclosed its presence by sinking a ship.

In September 1939, the Germans had available only about 60 U-boats, of which 30 were of the small 250-ton type (of limited endurance—suitable for coastal operations only) and 30 of the larger ocean-going type, of which 20 were of 500 tons and 10 were of 750 tons. German naval planning had not anticipated that England would enter the war at this time.

German Naval Planning—1939

Britain topped 5 years of appeasement by effectively surrendering Czechoslovakia at Munich in 1938. The British decision was based on the assessment that Britain was too defenseless against air attack to risk war with Germany. Yet, between Munich, when battle was refused, and September 1939, when battle was accepted, Great Britain's expenditure on armaments was only one-fifth that of Germany's. In the 1-year interval, German aircraft production was double that of the United Kingdom, the vulnerability of Britain to air attack had increased—not decreased.[33]

Near the end of 1938, Admiral Raeder presented Hitler with a choice of plans. One, based on the assumption that war was imminent, called for most of Germany's naval resources to be devoted to weapons of commerce warfare—U-boats, minelayers, raiders, and the like. The other, known as Plan Z, was a long-range program based on the assumption that war was not to be expected for 10 years. Under this plan, Germany would build a surface fleet technically and numerically superior to those of the Royal Navy.

Hitler ordered the implementation of Plan Z—he believed the same logic that dictated the British decision at Munich would continue to prevail in 1939 and form some time beyond. As a result, his navy was in no condition for anti-shipping warfare in 1939. Much of the naval resources were tied up in the battleships BISMARCK and TIRPITZ, which were nearing completion, and the building of the aircraft carrier GRAF ZEPPLIN.[34] At the outbreak of conflict his submarine force was excellent in quality, but too small in numbers to strike a knockout blow.

CONCLUDING REMARKS

The development of an ocean-going submarine force of the United States was an outstanding feature of the time interval between World War I and World War II. Pro-submarine developments in the United States and in Germany after 1935 had many similar features although designed for different oceans. During the 1930's both submarine forces were shaped by naval treaty tonnage agreements, both used advanced technology in boat construction, both trained intensively for warfare against warships, and both developed wolf-pack tactics and practiced countermeasures against active sonar.

In the above time interval, the outstanding sonar development was that of the German GHG. This conformal sonar, initially produced for capital surface ships was adapted for submarines in the late 1930's. The abandonment of electrically steered conformal sonar, pioneered by the United States in 1918, was an unfortunate decision.

Active sonar progress over the same time interval was also minimal. The mechanically-rotated transducer devised by LANGEVIN in 1917 had changed very little by 1939. The ping-listen searchlight-mode of operation persisted despite the time required for a 360-deg sweep. An example was the American QC, very similar to British Asdic gear. By 1939, major modifications included improved reliability and more sophisticated driver and receiving gear. Also, relatively unimproved was the depth-charge weapon. The increase in size of the "ashcan" to contain 700 instead 300 lb of explosive was the major change in this area over the 21-year time interval.

However crude and whatever were its shortcomings, one should not denigrate the role of U.S./U.K. active sonar. Once a submarine was classified and forced to submerge, in 1939 the fleet forces had the capability to attack with good chances for kill. But first the submarine had to come to the attacker—Asdic or sonar ranges were typically less than a mile. Winston Churchill in vol. 1 of his "History of the Second World War" concludes chap. 9 thus, "The Asdics did not conquer the U-boat; but without Asdics the U-boat would not have been conquered."

Hitler did not expect war with Britain in 1939. As a consequence his U-boat force was too small in numbers at the beginning of hostilities to strike a decisive blow. Mass production of submarines took time to organize—the blessed time delay enabled Britain and her allies to organize their defenses.

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